with the proteids termed by v. Fürth soluble myogen-fibrin, myosin, and myogen respectively. The fourth corresponds with the temperature at which white fibrous and yellow elastic tissue contract when heated.

We have concluded from this and many other facts that the contractions produced by heat are at basis caused by the heat-coagulation of the different proteids.

We have obtained corresponding results with mammalian muscle; here the contraction at 32—40° does not occur, and soluble myogen-fibrin is absent from the muscle plasma.

"Some Experiments with Cathode Rays." By A. A. C. Swinton. Communicated by Lord Kelvin, F.R.S. Received February 27,—Read March 11, 1897.

The extensive employment of the focus form of Crookes' tubes as the most efficient known means of generating X-rays, has rendered advisable the more complete investigation of the cathode ray discharge in tubes of this description.

Hitherto, the usual method of investigating the characteristics of a cathode ray discharge apart from its mechanical properties, and beyond what is visible to the unassisted eye, has been by allowing the rays to fall upon a screen of some brightly fluorescent material, such as glasses of various descriptions, or screens covered with fluorescent salts. With all of these the maximum amount of fluorescence appears to be produced by such comparatively weak cathode rays, that in some cases the special effects produced by the more powerful rays seem to be more or less entirely masked, while the well-known phenomenon of the fatigue of fluorescent substances, when exposed to the more active rays, conduces to the same result.

Surface Luminescence of Carbon when exposed to Cathode Rays.

I have found in some cases that by replacing the usual screen, made of or covered with fluorescent material, by one of ordinary electric-light carbon, much appears which was previously invisible. When a concentrated stream of powerful cathode rays are focussed upon a surface of carbon in this manner, a very brilliant and distinctly defined luminescent spot appears on the surface of the carbon at the point of impact of the rays, the remainder of the carbon remaining black. This luminescent spot seems to have a very close relation to the fluorescent spots on glass and on other fluorescent materials under similar influence. The effect is evidently a purely surface effect, as when the cathode stream is rapidly deflected by

means of a magnet, the luminescent spot on the carbon moves with no perceptible lag. Further, though, as is also the case with glass, the whole of the carbon becomes gradually heated to a considerable extent if much power be employed for a long period of time, these luminescent spots are instantaneously produced on carbon of very considerable brilliancy with but a comparatively low power. Again, just as glass is known to become fatigued under the influence of cathode rays, so that after a time it refuses to fluoresce so brightly as before, so carbon is similarly fatigued, though only after having been very strongly acted upon. Carbon, like glass, also recovers its property of giving a surface luminescence to some extent, though it does not seem to entirely recover, at any rate at all rapidly.

That the rays which produce the luminescence of the carbon are the same rays that cause fluorescence of the glass can be proved by deflecting the rays from the carbon on to the glass by means of a magnet.

As it is exceedingly difficult, if not impossible, to obtain carbon plates which do not contain hydrocarbons and other volatile matter which are rapidly given off and reduce the vacuum very quickly when the carbon becomes at all heated, it is necessary to keep the tube connected to the mercury pump, so that the vacuum can be restored after each experiment. This arrangement was followed in all the experiments described below, except where specific mention is made to the contrary.

Apparent form of the Cathode Ray Discharge in a Focus Tube.

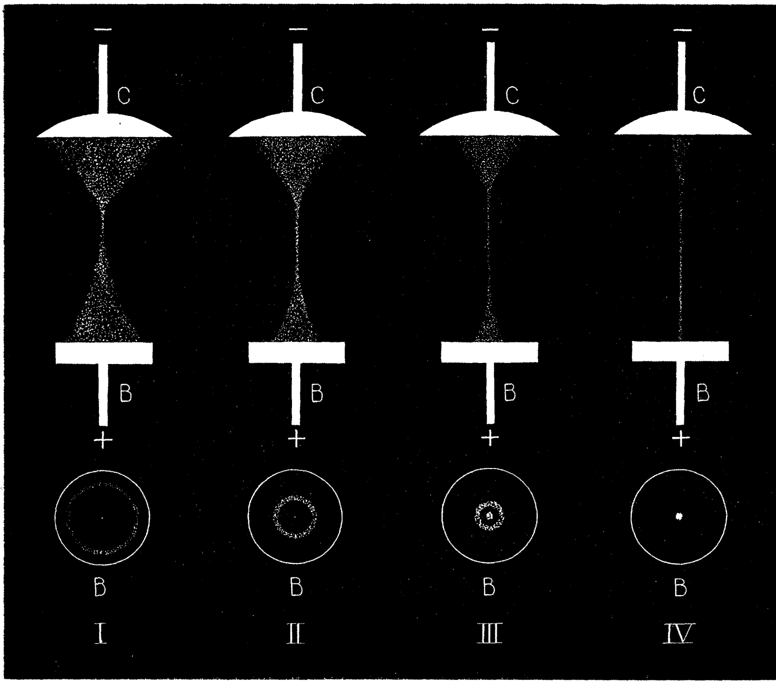
As is well known, in tubes of the ordinary focus type with a single spherical concave cathode, the rays coming off normally to the cathode surface appear to converge in more or less of a cone to a focus, and if the vacuum be not too high, to diverge again immediately in another cone upon the other side of the focus. At higher vacua the rays, after passing the focus, do not appear to diverge again at once, but seem to form themselves into a description of thread which connects the convergent and divergent cones, and is longer or shorter according as the vacuum is higher or lower. The angle of the divergent cone appears, however, to be always proportional to that of the convergent cone. The focus, or perhaps more correctly, the point at which this thread commences, seems always to be more distant from the cathode than the centre of curvature of the latter, but the variation in this respect seems to be less and less the higher the exhaustion. This is no doubt due to the mutual repulsion of the rays, and accords with the assumption that the rays consist of charged particles, which travel more and more rapidly the higher the exhaustion. Probably for the same reason, cathodes that are

only slightly concave, focus further in proportion beyond their centres of curvature than do deeply concave cathodes, for the same vacuum.

Apparent Hollowness of the Divergent Cone of Rays.

When the divergent cone is thrown upon a thin platinum disc, as in the ordinary focus tube, and sufficient electric power—say, from a 10-in. Ruhmkorff coil—is employed, the platinum quickly attains to a red heat. With platinum, either the whole disc becomes uniformly heated, or in the event of the diameter of the cone of rays where it strikes the platinum being small compared with the area of the platinum, that portion of the platinum covered by the base of the cone becomes uniformly heated to a higher temperature than the remainder. This is as much as can usually be seen with platinum, though rather more is sometimes visible with aluminium; but if instead of either metal the disc is made of ordinary electric-light carbon, I have found that the luminescent portion of the carbon, instead of comprising the whole disc, or consisting of a uniformly heated circle, will in some cases take the shape of a brilliantly luminescent and apparently white-hot ring, with a well-defined dark, and seemingly quite cold, interior. As the dimensions of the cone of rays are increased or decreased by decreasing or increasing the vacuum, the luminescent ring will be found to increase or decrease correspondingly in diameter, at the same time being brighter when small than when large. Further, when the ring is very small it will usually have a very brightly luminescent central spot, with a dark intervening portion between this spot and the ring, and when the vacuum is further increased the ring will gradually close in upon the spot until only the latter remains.

Figs. 1, 2, 3, and 4 show diagrammatically these hollow effects, as produced by spherical aluminium cathodes, 1·125 in. diameter and 0·708 in. radius of curvature, for four different degrees of vacuum, 1 being the lowest and 4 the highest exhaustion. The upper portion of each of these figures represents the general appearance of the cathode discharge between the spherical concave aluminium cathode C at the top, and the carbon anti-cathode B at the bottom, as accurately as it is possible to represent evanescent coloured appearances in monochrome. The other appearances, due to the dark space and fluorescence of the glass, are omitted for the sake of simplicity. Beneath each of the elevational views of the cathode discharge will be found a plan view of the carbon anti-cathode, showing for each condition of vacuum the effect of the cathode discharge upon the carbon anti-cathode, in forming a brightly luminescent hollow ring, gradually decreasing in diameter as the vacuum is increased, until it centres on a point, as already mentioned.



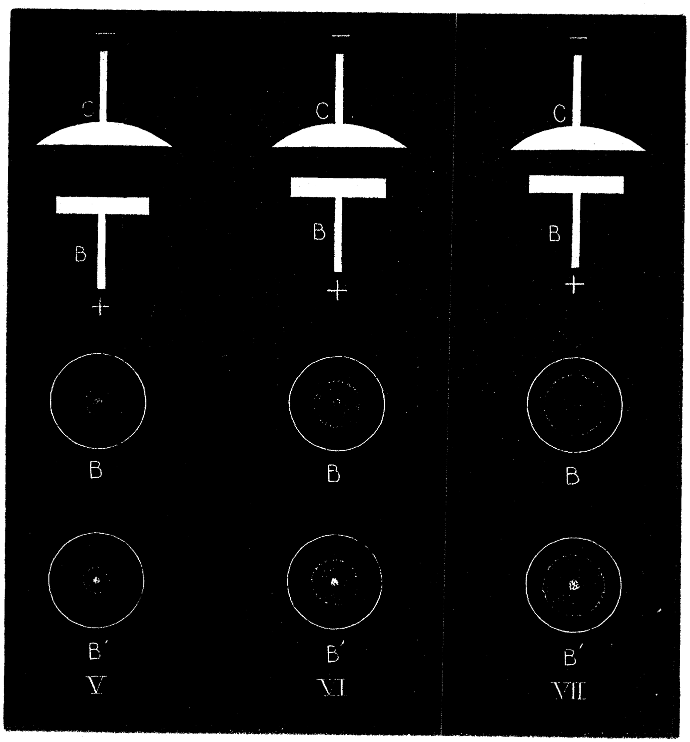
It may further be remarked that the diameter of the luminescent ring may be increased or diminished, or finally reduced to a point, without altering the degree of vacuum, by moving the anti-cathode away from or towards or finally into the focus of the cathode stream, the appearance of the ring in each of these cases being practically similar to those shown in the figures for a uniform distance with varying vacuum. When the anti-cathode surface is not at right angles to the line of the discharge, the ring, in place of being circular, takes the proper form of a conic section. The holding of a magnet near the tube distorts the ring from a circular shape and moves its position on the carbon.

From these experiments it appears that the diverging cone of cathode rays acts as though it were not of uniform density throughout its section, but, at any rate in some instances, as if it were completely hollow. This fact does not appear to have previously been noted.

Apparent Hollowness of the Convergent Cone of Rays.

The apparent hollowness of the divergent cathode ray being thus established, it was thought desirable to ascertain whether the same

condition of affairs exists in the converging beam of rays between the cathode and the focus. Owing to the well-known difficulty of getting any discharge to pass when the distance between the electrodes is less than the thickness of the dark space, and to the disturbing effect which the anti-cathode screen is found to have when brought within the focus of the cathode, especially with high vacua, this question was found much more difficult to decide than that of the hollowness of the divergent cone. However, that the convergent cone also acts under certain circumstances as though it were almost completely hollow, and acts generally as if it had a considerable tendency towards hollowness at low vacua, was also finally fully determined. The lower portions of figs. 5, 6, and 7 show the bright



ring appearance upon the carbon anti-cathode at two different degrees of exhaustion, B being higher vacua than B′, and with the anti-cathode at the three different distances from the cathode within the focus of the latter, as shown in the upper part of each figure. As will be observed in this case, the degree of vacuum is found not to appreciably affect the dimensions of the figure, though it should

be stated that the vacua in each case were comparatively low, as vacua as high as those employed when the anti-cathode was outside the focus, gave no results at all. As will be seen, however, the diameter of the luminescent ring is affected by the degree of proximity of the anti-cathode to the cathode, being larger when the distance is small than when it is great; while in every case there is a decided tendency towards hollowness, though usually with some slight internal luminescence and with a bright central spot, while in one case, when the anti-cathode was very close to the cathode and the vacuum was comparatively high, the ring is seen completely hollow, and there is no central spot.

A convenient form of tube for showing the apparent hollowness of both the divergent and convergent cone of cathode rays is shown in fig. 8, where the anti-cathode disc B, made of electric-light carbon, is supported upon a small carrier which slides upon the bottom of the tube, and is connected to the anode terminal D by means of two aluminium wires, each of which have a ring at their extremity through which they respectively pass. As the carbon, under the action of the cathode rays, gives off hydrocarbon vapour, it is necessary, as already mentioned, to try all these experiments with the tube connected to the mercury pump; but with this connection made through a slightly flexible mercury joint it is possible by inclining and gently tapping the tube to bring the anti-cathode to any desired position either near or far away from the cathode. For experiments upon the divergent cone, it is not necessary that the anti-cathode screen should be connected to the anode terminal, and, consequently, the sliding aluminium wires inside the tube are not required. They are, however, necessary when observations are to be made on the convergent cone between the cathode and the focus, as the anti-cathode screen when placed within the focus must be connected to the anode, or it appears to get negatively charged and acts itself as an additional cathode, throwing cathode rays in all directions.

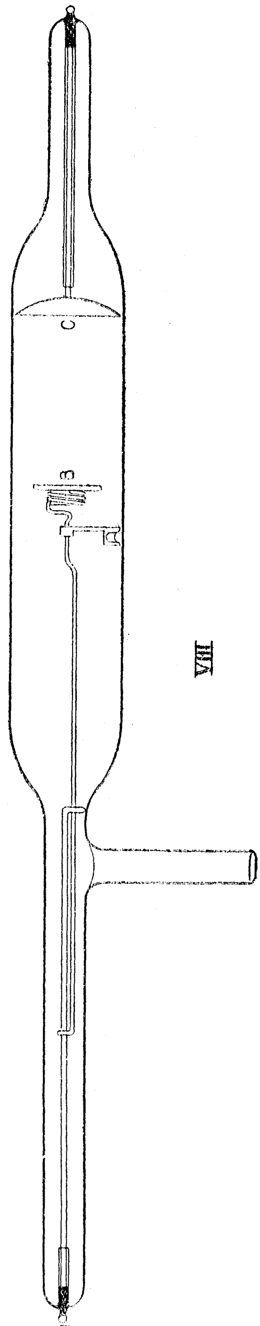
It may here be mentioned that the fatigue of the carbon already alluded to renders necessary some precautions in carrying out the above-mentioned experiments, as otherwise the observer may be misled into thinking that a beam of cathode rays is effectively hollow when this is not the case, owing to the centre of the carbon covered by the beam having been fatigued by some previous experiments. By taking the precaution, however, of deflecting the cathode beam by means of a magnet on to various portions of the carbon screen, such errors may be avoided. It should also be noted that these hollow effects appear only to be obtained with fairly short focus cathodes, such as are usually employed in X-ray focus tubes, that is to say, with cathodes whose diameter is large as compared with their radius of curvature, so that the rays converge and diverge

rapidly to and from the focus. With comparatively flat, long focus cathodes the cones do not show any signs of being hollow, and produce a uniformly luminescent spot upon the carbon of larger or smaller diameter, according to the conditions of vacuum and the position of the screen.

For instance, while cathodes 1·125 inches diameter and 0·708 inch radius of curvature gave in the manner described distinctly hollow convergent and divergent cones, a cathode 1 inch diameter and 1·5 inches radius of curvature gave convergent and divergent cones that appeared to be uniformly solid under all conditions.

The Rays cross at the Focus with no Rotation.

In order to investigate the cathode rays in a focus tube still further, and more especially in order to discover whether the various rays from the cathode cross one another at the focus, or diverge again without crossing, and also in order to discover whether there is any twist or rotation of the rays, similar to what has been observed in the case of rays focussed by magnetism,* a tube was constructed similar to that used in the previous experiments, with a carbon anti-cathode which was also the anode, fixed at the opposite side of the focus from the cathode, with the focus about equally distant between it and the cathode. The peculiarity of this tube consisted in the fact that a sector of the aluminium cathode, equal to one-eighth of the total area of the cathode, had been entirely removed, as shown at C, fig. 9. It was expected that on using this tube, with the proper degree of vacuum to form a well-defined ring on the anti-cathode screen, that a portion of the ring, corresponding with



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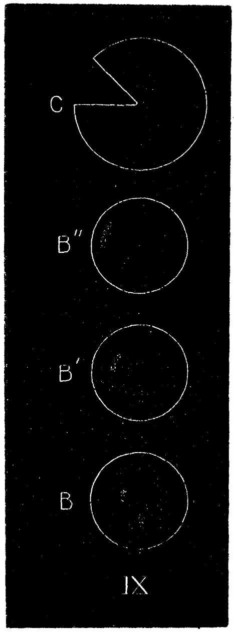
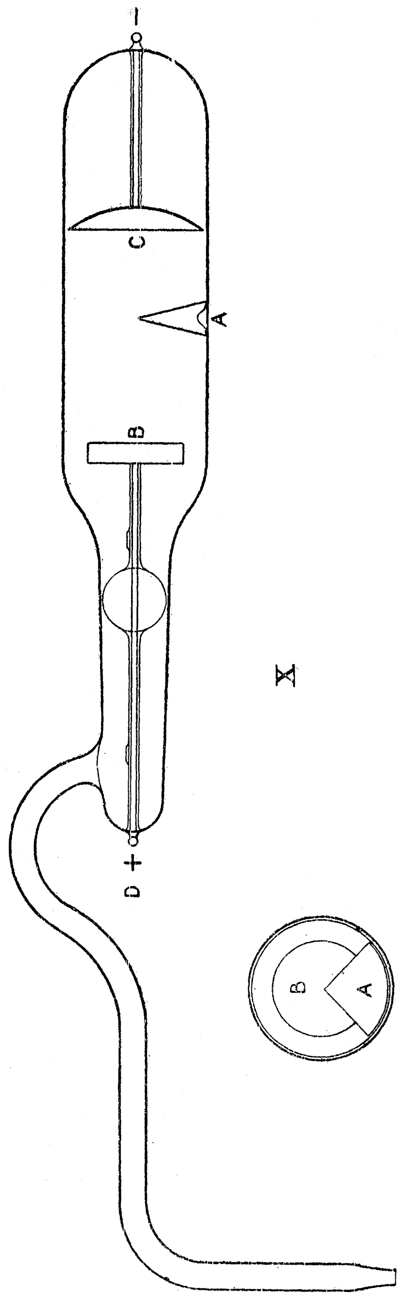
* See experiments by K. Birkeland, 'Electrical Review,' June 12, 1896.



the amount of the cathode cut away, would be found wanting; and that by the position of this gap in the ring it would be possible to ascertain whether the rays crossed at the focus, and whether there was any rotation. What actually was observed is shown for three different conditions of vacuum in fig. 9, B being for the highest, and B″ for the lowest vacuum. As will be seen, the expected gap in the ring was obtained, but with the unexpected addition that the dimensions of this gap, instead of being only one-eighth of the circumference of the ring, was seven-eighths of the circumference. In fact, the amount of ring shown corresponded not with the seven-eighths of the remaining cathode surface, but with the one-eighth of the cathode that had been removed. The portion of ring that did appear was of a length corresponding exactly to the arc of the removed sector of the cathode, according to its greater or lesser nearness to the centre with different conditions of vacuum; and as the portion of ring was in each case exactly in line with the portion of cathode that had been cut away, it would appear that there is no rotation of the cathode beam as a whole, that the rays do cross at the focus; and, further, that when the hollow convergent cone is, as it were, split in this manner, some unexplained action, similar in effect to the existence of a circular surface tension, causes the gap to widen out and the

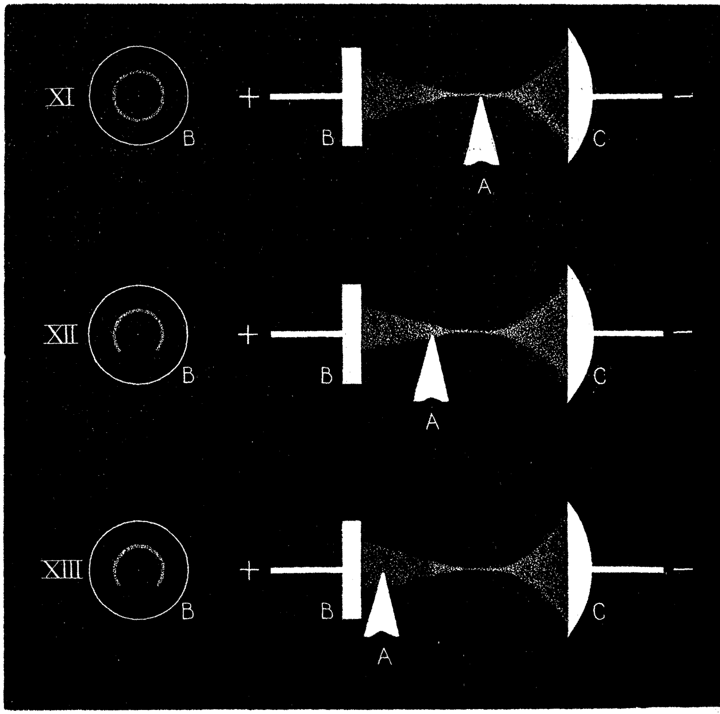
remaining portion of the ring-shaped section of the cone to contract correspondingly, without, however, altering its diameter.

In order to further investigate the matter another tube was made, as shown in fig. 10, in which the concave cathode was complete; but the interior of the tube was furnished with a small movable piece of aluminium, A, which by shaking could be moved up and down the tube between the cathode C, and anti-cathode B, and which, while not quite reaching the centre of the tube, would fill up very nearly one quarter of the circular sectional area of the latter.



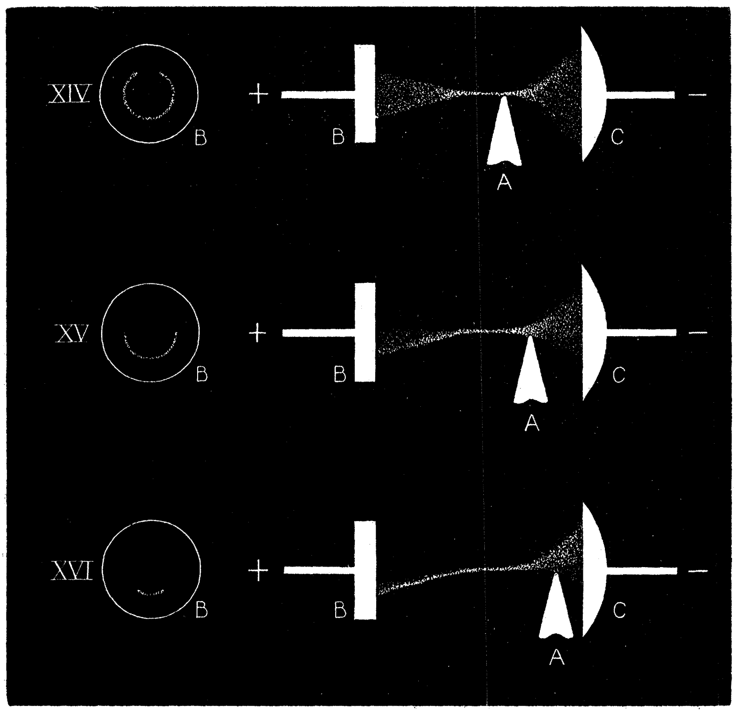
With this arrangement of tube, with the aluminium obstacle placed just at the focus, as shown in fig. 11, the point of the obstacle just missing the cathode rays, a complete ring was formed on the carbon anti-cathode. On moving the obstacle slightly into the divergent cone, exactly one quarter of the ring on the anti-cathode failed to appear, as shown in fig. 12, and on the obstacle being further moved in the same direction the result was not altered, as shown in fig. 13.

As in each of the latter two cases there was no displacement of the gap in the ring, the above showed that there is no rotation of the divergent cathode cone.



Experiments were next tried with the aluminium obstacle, moved so that its point just entered the converging cone of cathode rays, when a small portion of the ring was cut out, but on the opposite side, as shown in fig. 14, this confirming the previous experiments, which showed that the rays cross one another's paths at the focus without rotation. Upon moving the aluminium obstacle a little nearer to the cathode, so that its point entered still further into the convergent cathode beam, one half of the ring disappeared, as in fig. 15, while when the obstacle—which, it should be remembered, blocked only one quarter of the circular area of the tube—was brought close up to the cathode, only about one quarter of the ring remained, as in fig. 16.

Further experiments were tried with the aluminium obstacle both in the divergent and convergent cones, but with the tube exhausted to different degrees of vacuum, the result being as shown in figs. 17 and 18, in which in each case B shows the highest vacuum and B″ the lowest, from which it will be observed that when the obstacle was in the divergent cone, a portion of the ring was cut off exactly proportional to the angle subtended by the sides of the obstacle; while when the obstacle was placed in the convergent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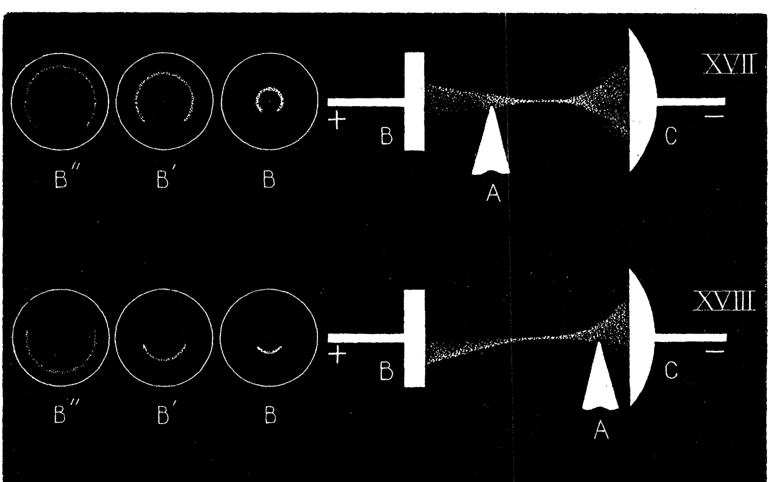
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cone, a much larger proportion of the ring was cut off in each case, this being much more marked with a high vacuum when the diameter of the ring was small, than with a low vacuum when the diameter of the ring was large.

Convergent and Divergent Cones produced by Magnetic Focussing.

In order to discover whether the apparent hollowness of the convergent and divergent cones of cathode rays as above observed, when the focussing was performed by means of a spherical cathode, was in any way due to the concave form of the cathode or to the fact that the rays were converging or diverging, experiments were tried with a tube having a flat aluminium cathode, the rays being caused to converge to a focus by means of a powerful electro-magnet in the manner described by the writer in his paper on "The effects of a strong magnetic field upon electric discharges *in vacuo*." *

The arrangement is shown in fig. 19, the carbon anti-cathode screen, B, being movable, and not connected to the anode D, which was contained in an annex to the tube. By increasing or decreasing the power of an electro-magnet M, by moving it nearer to or further away from the tube, and by moving the anti-cathode screen up and down the tube, the cathode rays could be focussed on the anti-cathode screen so as to form a circle of any desired size, the focus, which appears to be exactly on the pole of the magnet, being, of course, always beyond the anti-cathode.

In order similarly to investigate a divergent cone of cathode rays magnetically produced, a circular coil of wire, E, was employed instead of the magnet in the manner recently described by Professor Fleming.† This coil, which had 72 turns of No. 18 S.W.G. size wire, was supplied with 20 to 25 amperes of current from a storage battery. It focussed the cathode rays at a point exactly central to its own plane, from which they again diverged on to the anti-cathode screen.

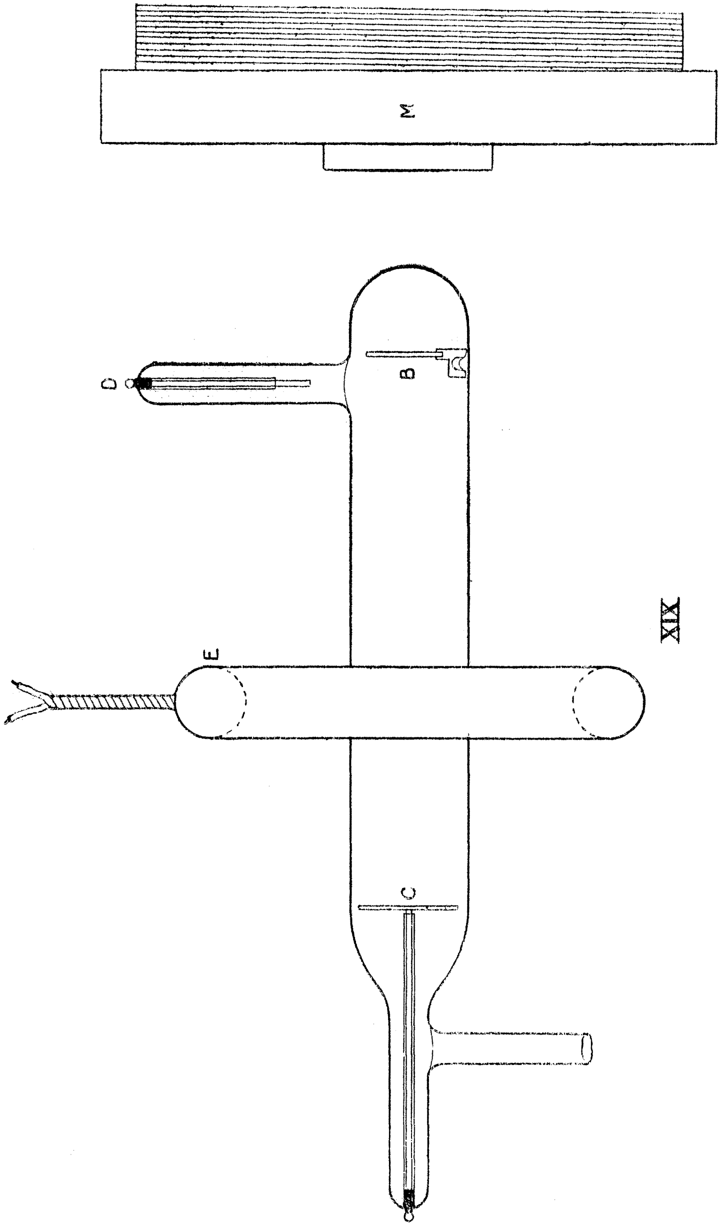
With convergent and divergent cones of rays produced magnetically in the above manner, there was no difficulty in showing that, under suitable conditions, these cones acted as if they were hollow, giving bright rings of varying sizes, sometimes with and sometimes without bright central spots, upon the carbon anti-cathode screen, exactly similar in appearance to those obtained with the concave cathode.

Further observations were as follows:—

In some instances, two concentric hollow rings were observed, especially with a low vacuum, when the magnet was suddenly turned

* 'Roy. Soc. Proc.,' 1896, vol. 60, p. 179.

† 'Electrician,' January 1, 1897.



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on or off. The rings are probably not simultaneous, but successive, but this cannot be detected with the unaided eye.

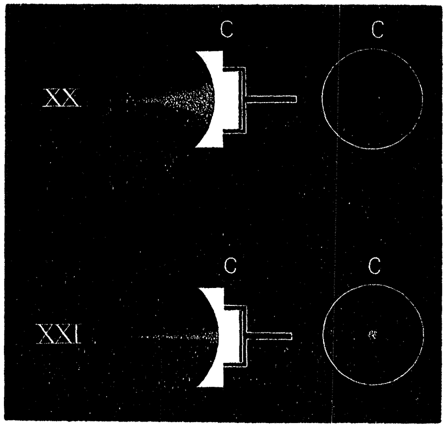
With a high vacuum, and the magnet so arranged as to focus the

rays accurately upon the carbon, a small bright spot appears at first; as the vacuum goes down this point becomes larger and fainter, but still solid. Suddenly it becomes hollow and brighter; then, as the vacuum falls still further, the ring becomes solid again, though larger and more faint than before; finally it disappears. After this stage it can be reproduced momentarily, without alteration to the vacuum, by switching the magnet on and off suddenly, when it is usually hollow, but sometimes solid.

The Convergent Cone at Higher Vacua.

As has been mentioned, the carbon anti-cathode screen was found useless for investigating the convergent cone of cathode rays at anything but a very low vacuum, by the reason of the well-known difficulty in getting any discharge to pass when the distance between the electrodes is less than the thickness of the dark space, and for the further reason that if the anti-cathode screen was not connected to the anode, it became itself negatively charged and acted as an additional cathode when brought into the space between the cathode and the focus.

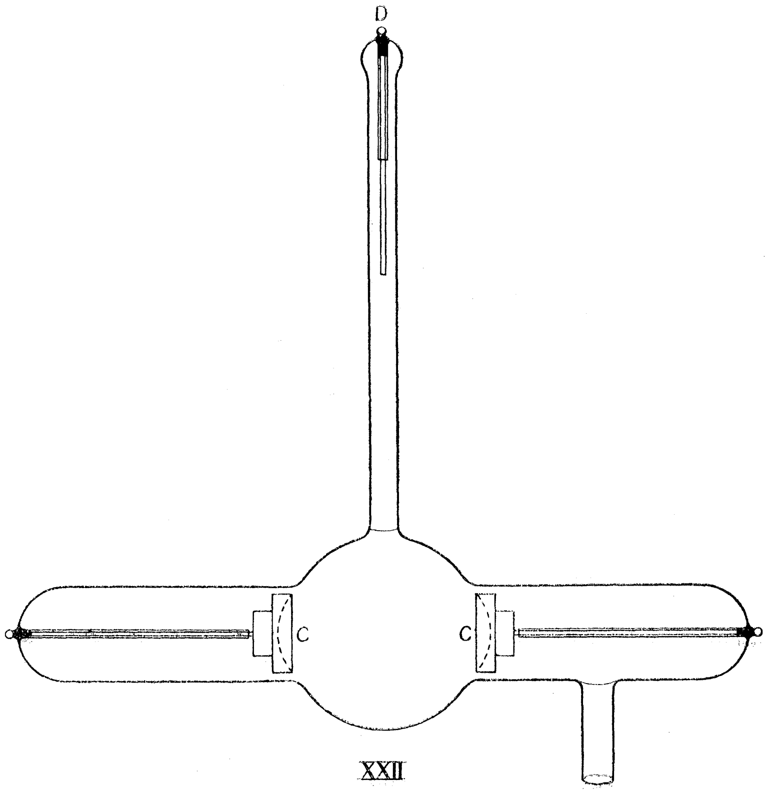
Under these circumstances, it was thought that possibly some additional information might be obtained with regard to the form of the convergent cone at high vacua, by making the concave cathode itself of carbon. A tube was therefore constructed having a concave carbon cathode, the diameter of which was 1 inch, and the radius of curvature 0·75 inch. The appearance of the cathode with this tube is shown for a fairly high vacuum in fig. 20, in which the cathode itself is shown in section, so as to let the form of the discharge be better seen. As will be observed under this condition of vacuum, which was too high to show any divergent cone, the cone of convergent rays appears to be contracted in diameter at its base, and to come off from the central portion of the cathode only, the remaining surface of the cathode being apparently inactive. This was found to be still more the case at higher vacua, as will be seen from fig. 21, which shows in a similar manner the form of the cathode discharge in a tube exhausted to a very high vacuum. In this case, as will be observed, the whole of the cathode rays appear to come off from a very small spot in the centre of the cathode. Further, that this small spot is, at any rate, the source of most, if not all, activity, was evident from the fact that it became luminescent exactly in the same manner, but in a less degree, than had previously been observed with a carbon surface upon which cathode rays were concentrated. Whether this surface luminescence of the cathode carbon at the point where the cathode rays leave it is due to the violent tearing away of particles of carbon, or to some other cause, it is difficult to say, but



the fact that at high vacua the cathode rays come off entirely or, at any rate, almost entirely from only a very small portion of the centre of the cathode, explains the observed fact that within limits large cathodes have no advantage over small cathodes in X-ray tubes.

During the carrying out of the above experiments with a carbon cathode, very bright sparks were occasionally seen coming off the cathode and passing through the focus, and it was consequently thought that possibly by placing two concave carbon cathodes facing one another, such particles, by being caused to rebound backwards and forwards continuously between the two, might render the form of cathode stream visible at very high vacua when the stream itself becomes otherwise invisible.

With this view, a tube was made as shown in fig. 22, in which two concave carbon cathodes CC, similar to those employed in the last experiment, were placed exactly opposite one another, so that a prolongation of the focus of either one would pass through the centre of the other. The anode, D, was placed in an annex, as shown in the illustration, and the two cathodes were connected together by means of a wire outside the tube. At a very high exhaustion, this tube gave very beautiful effects, and showed clearly the form of the cathode discharge at a degree of exhaustion when it is usually in itself quite invisible. Immediately on the current being turned on and the discharge passing, a straight and thin stream of bright golden coloured particles of apparently incandescent carbon passed between small luminescent spots at the centres of each cathode, as shown in fig. 23. This did not last for more than a second, when, owing no doubt, to the rapid fall of vacuum, the appearance changed to that shown in fig. 24, and the incandescent particles of carbon could be seen passing backwards and forwards along the convergent and



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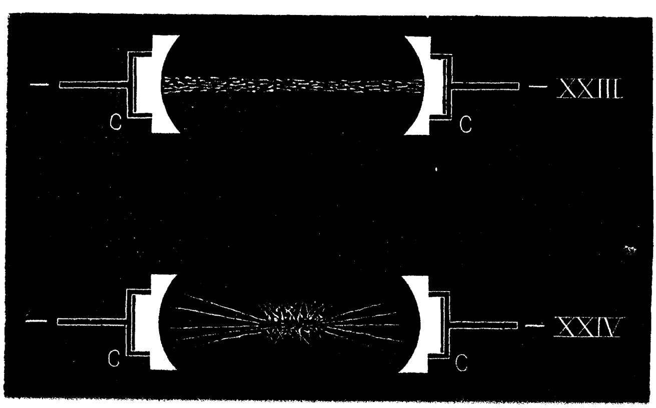


divergent cones of cathode rays, which, at the lower vacuum, proceeded from both cathodes, and spluttering in the centre, where the particles going in opposite directions collided. This appearance

lasted for some seconds, becoming gradually fainter as the vacuum fell. By re-exhausting the tube with the pump, however, the original appearance shown in fig. 23, as also the appearance shown in fig. 24 could be produced as often as desired. Apparently the particles of carbon become heated to incandescence either by the action of the cathode rays upon them while they are flying through space, or by their friction in passing through the residual gas, and possibly by their mutual collisions, for in the stage shown in fig. 24, when the cathodes themselves show no luminescence, the flying particles appear to be most intensely luminescent when in the centre of the tube. It may be mentioned that after this experiment had been repeated several times, the glass of the tube became perceptibly blackened, which, taken with the fact that a similar tube with cathodes of aluminium showed no stream of bright particles, goes to show that the particles consist of carbon torn off the surfaces of the cathodes.

The Production of X-Rays.

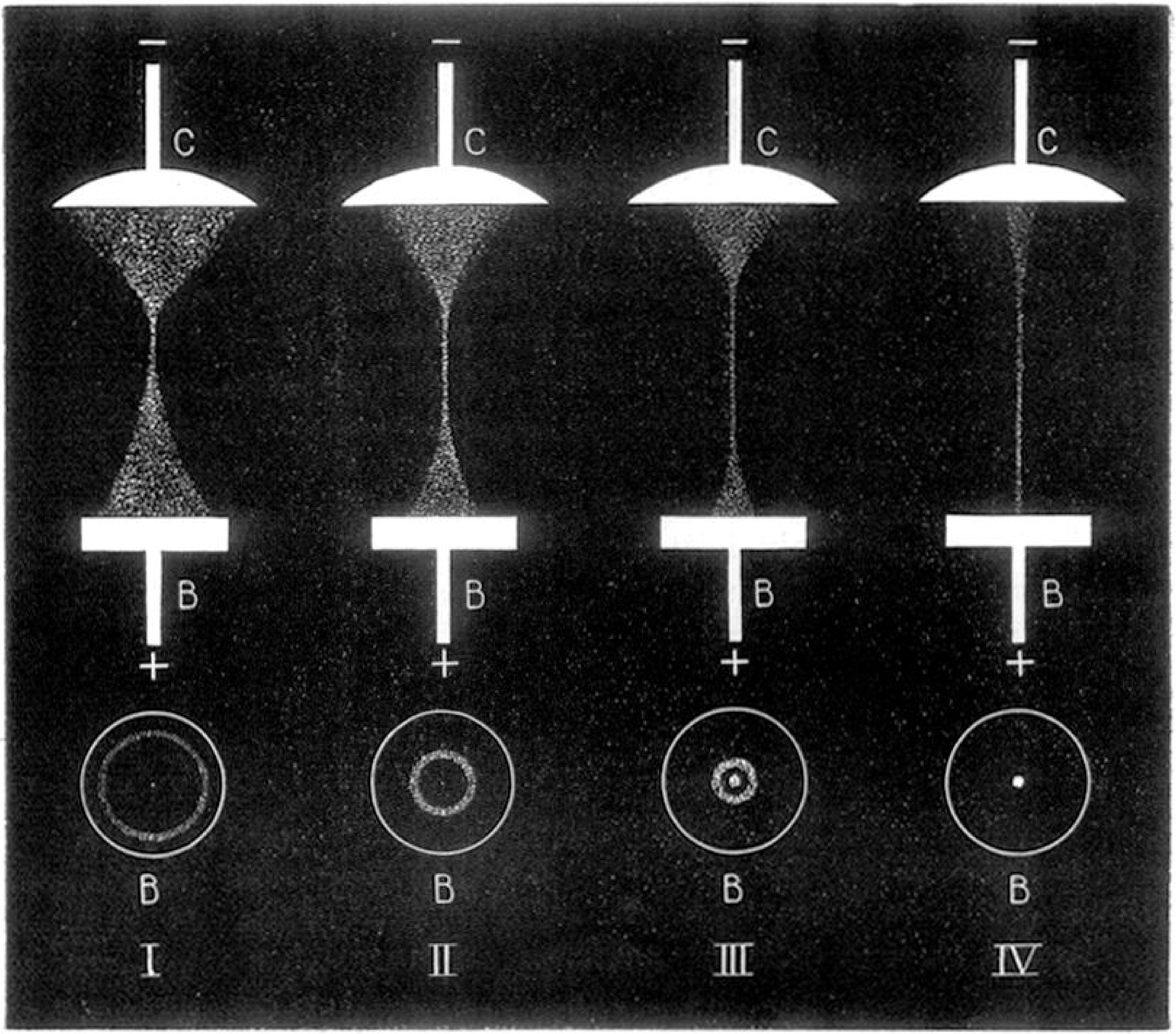
The tube, fig. 22, with carbon cathodes was found to produce feeble X-rays, which, when observed with a fluorescent screen, appeared to come either from the fluorescent glass of the bulb or from the travelling particles of carbon.

In order to ascertain whether it is necessary that the cathode rays should fall on solid matter in order to produce X-rays, another tube was constructed, similar in all respects to that shown in fig. 22, with the exception that the two cathodes were made of aluminium.

It was thought that with this tube the opposing streams of cathode rays might possibly produce X-rays at the point where they met. This does not, however, appear to be the case, as though this tube, when exhausted to so high an extent that the alternative spark in air leapt fully 8 inches, gave X-rays in considerable quantity, these rays appeared to come entirely from portions of the glass of the tube that were covered with green fluorescence, and not at any rate appreciably from the central point between the two cathodes, where the opposing streams of cathode rays would meet one another.

It seems, therefore, that X-rays can only be produced by cathode rays when these strike solid matter.

In conclusion I wish to mention how much I owe in carrying out these experiments to the assistance of Mr. J. C. M. Stanton and Mr. H. Tyson Wolff, who have made and exhausted all the tubes, and to whom I am also indebted for many valuable suggestions.



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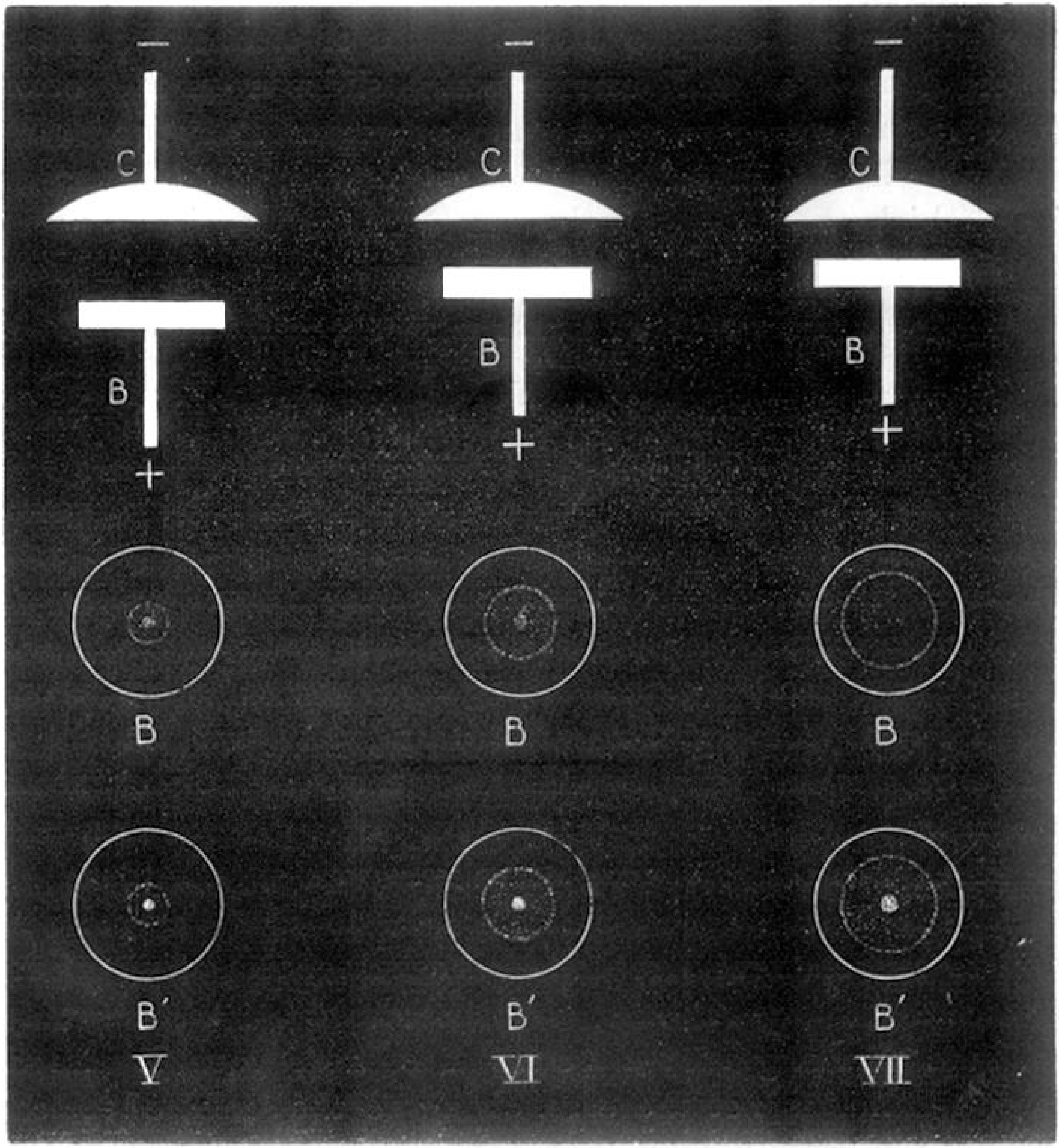
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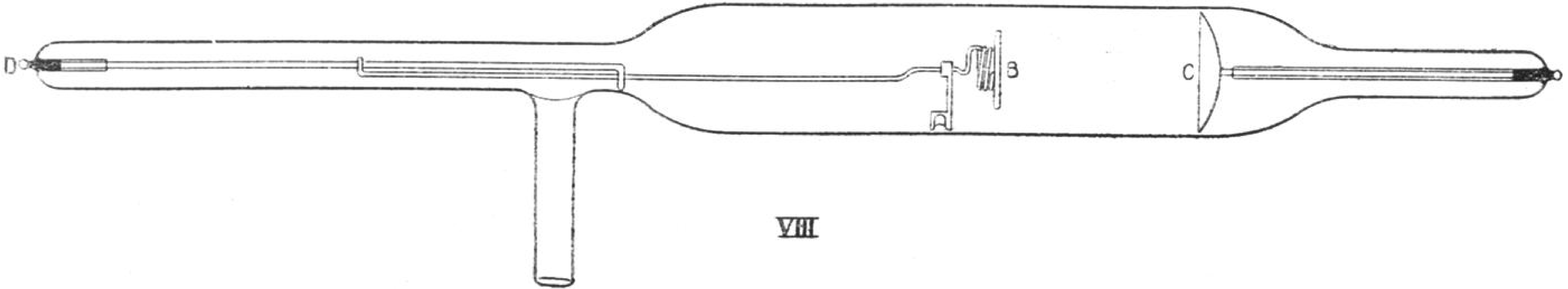

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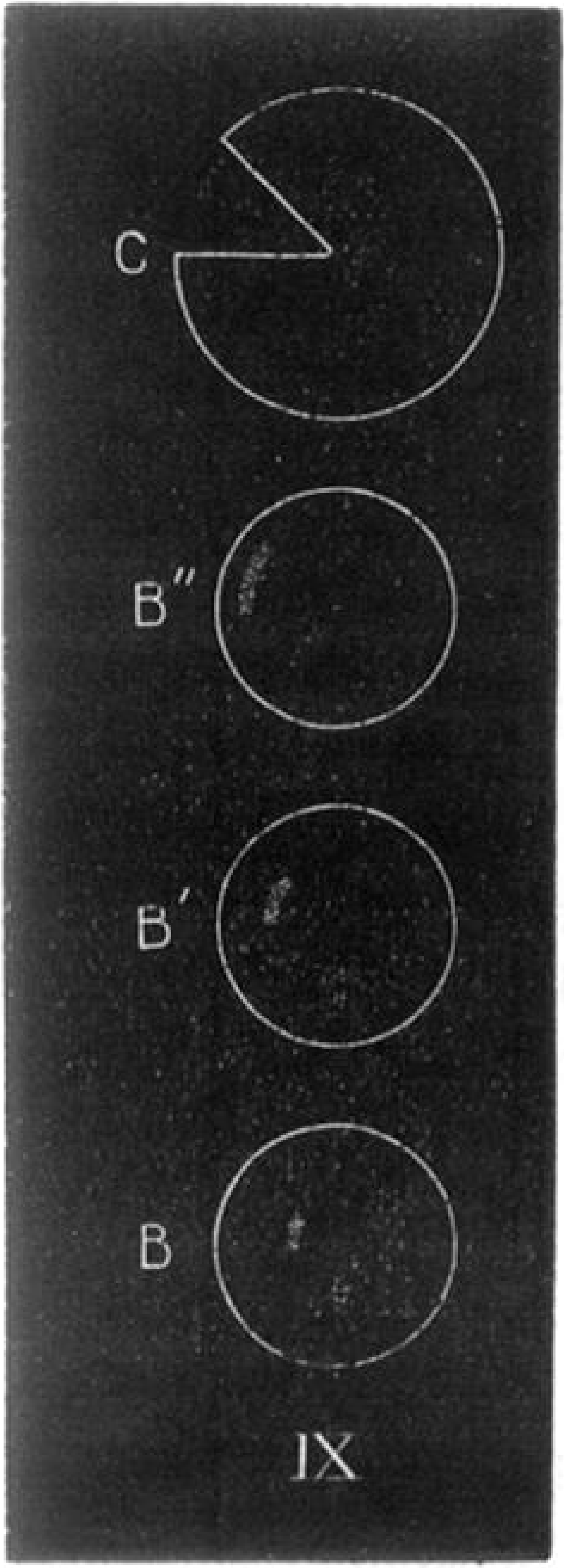
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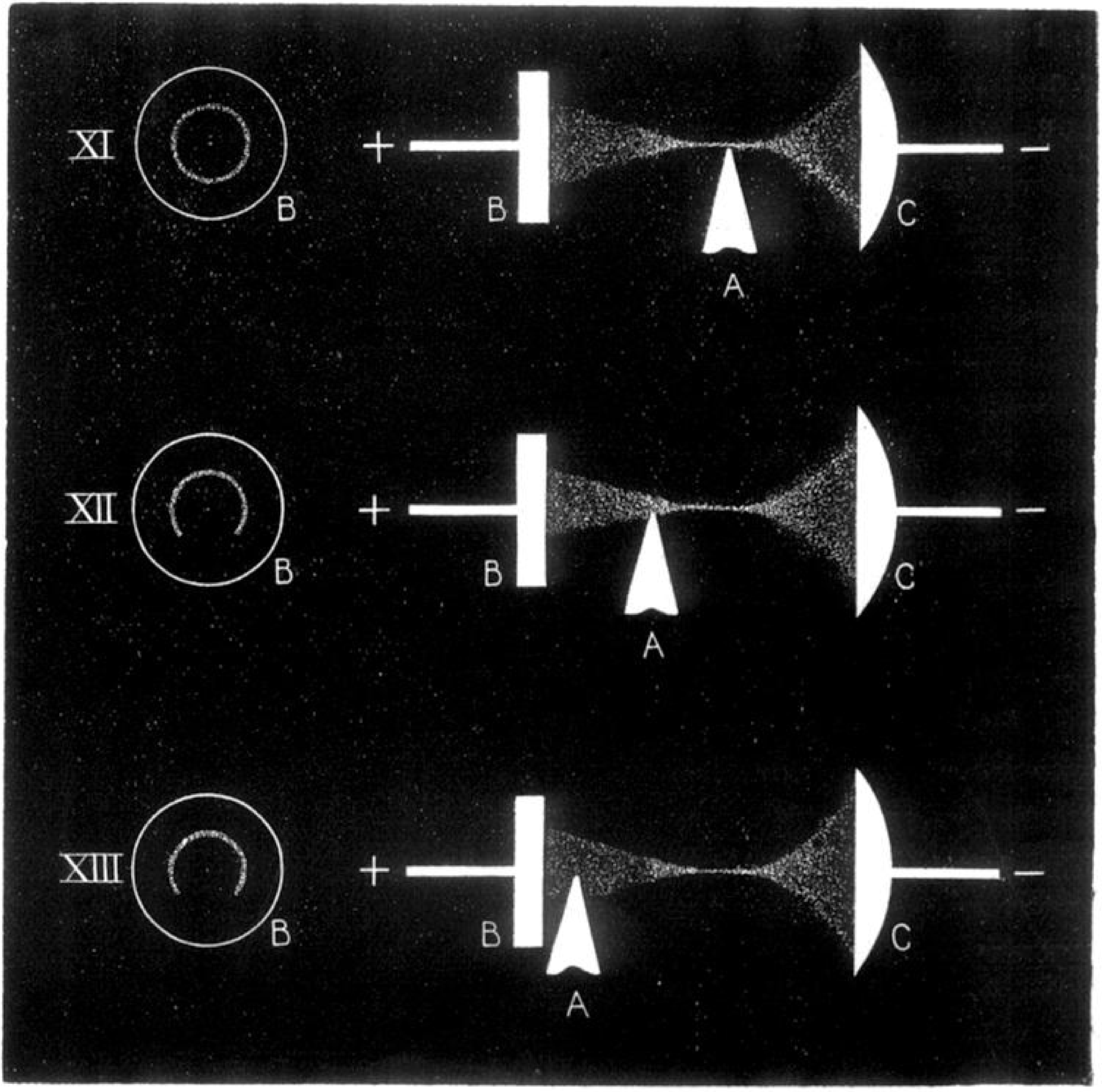
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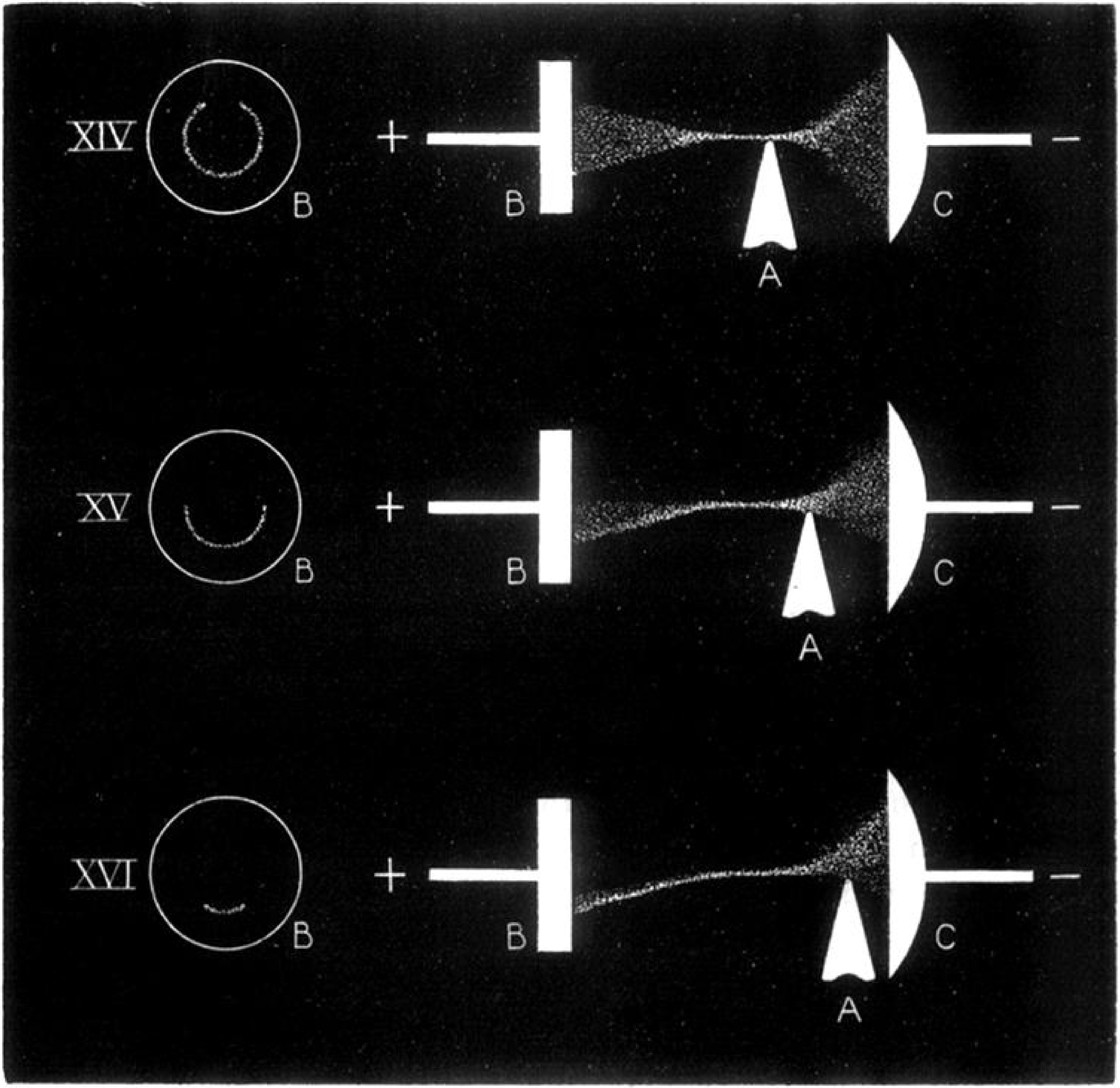
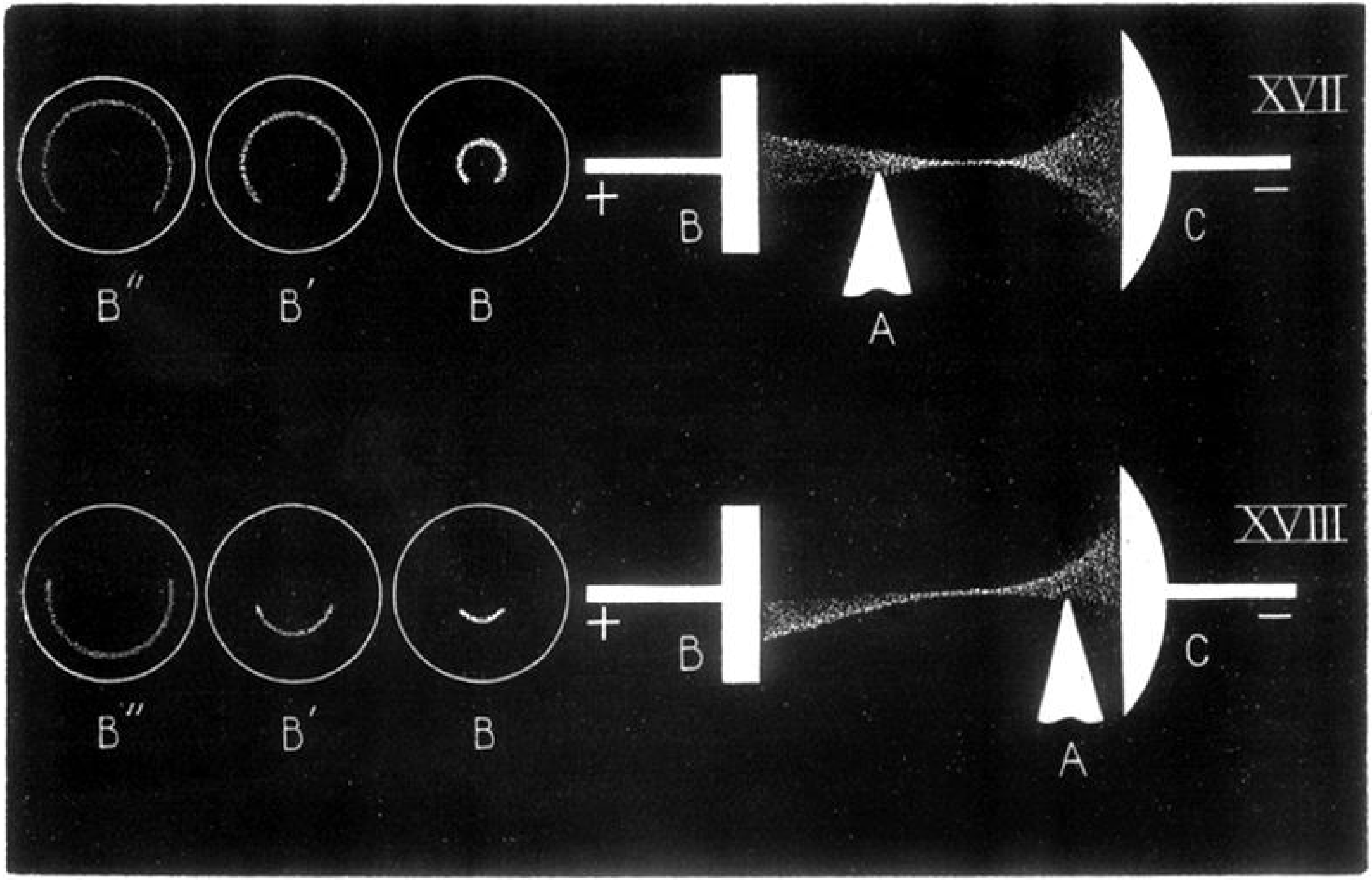
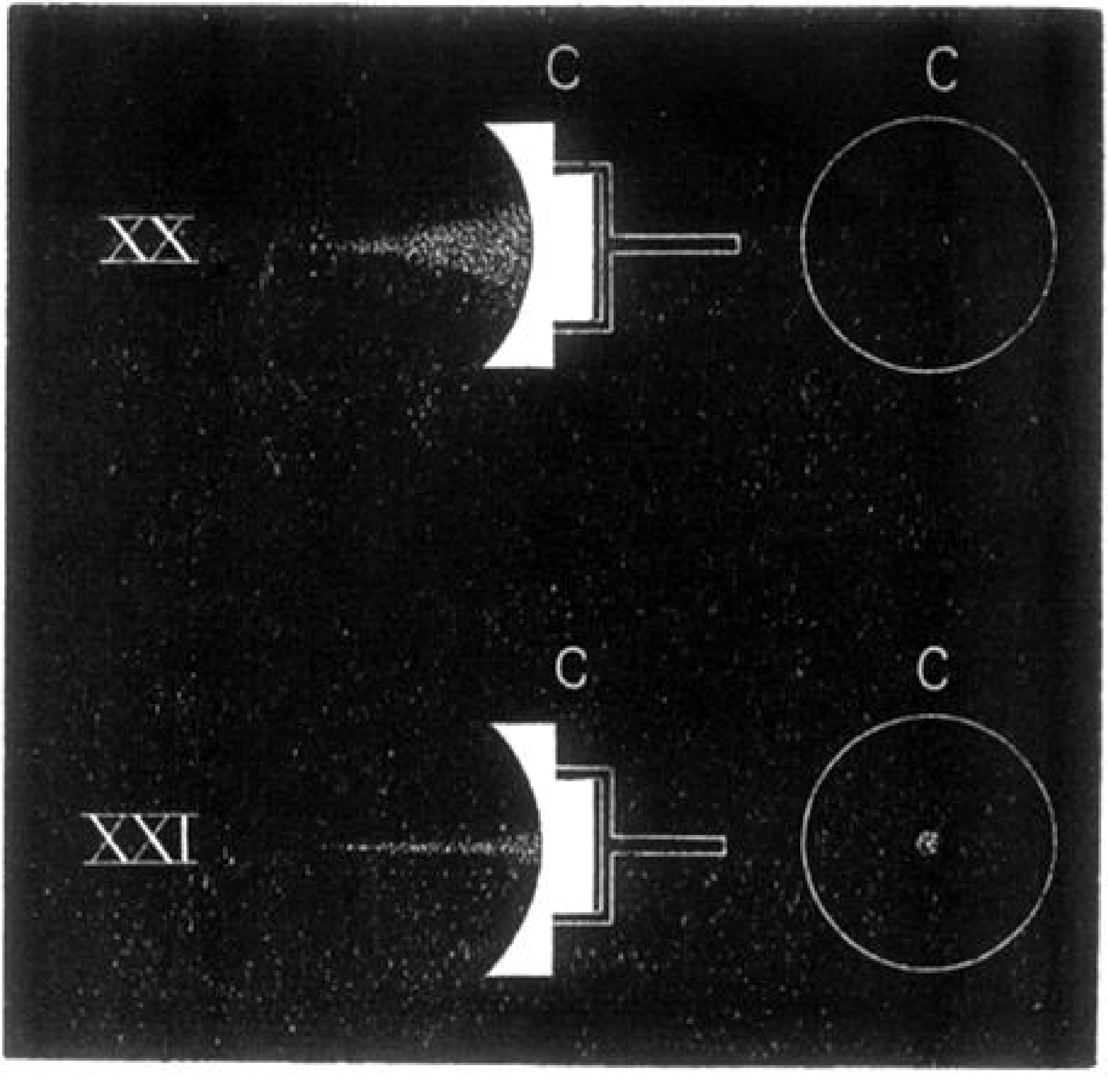
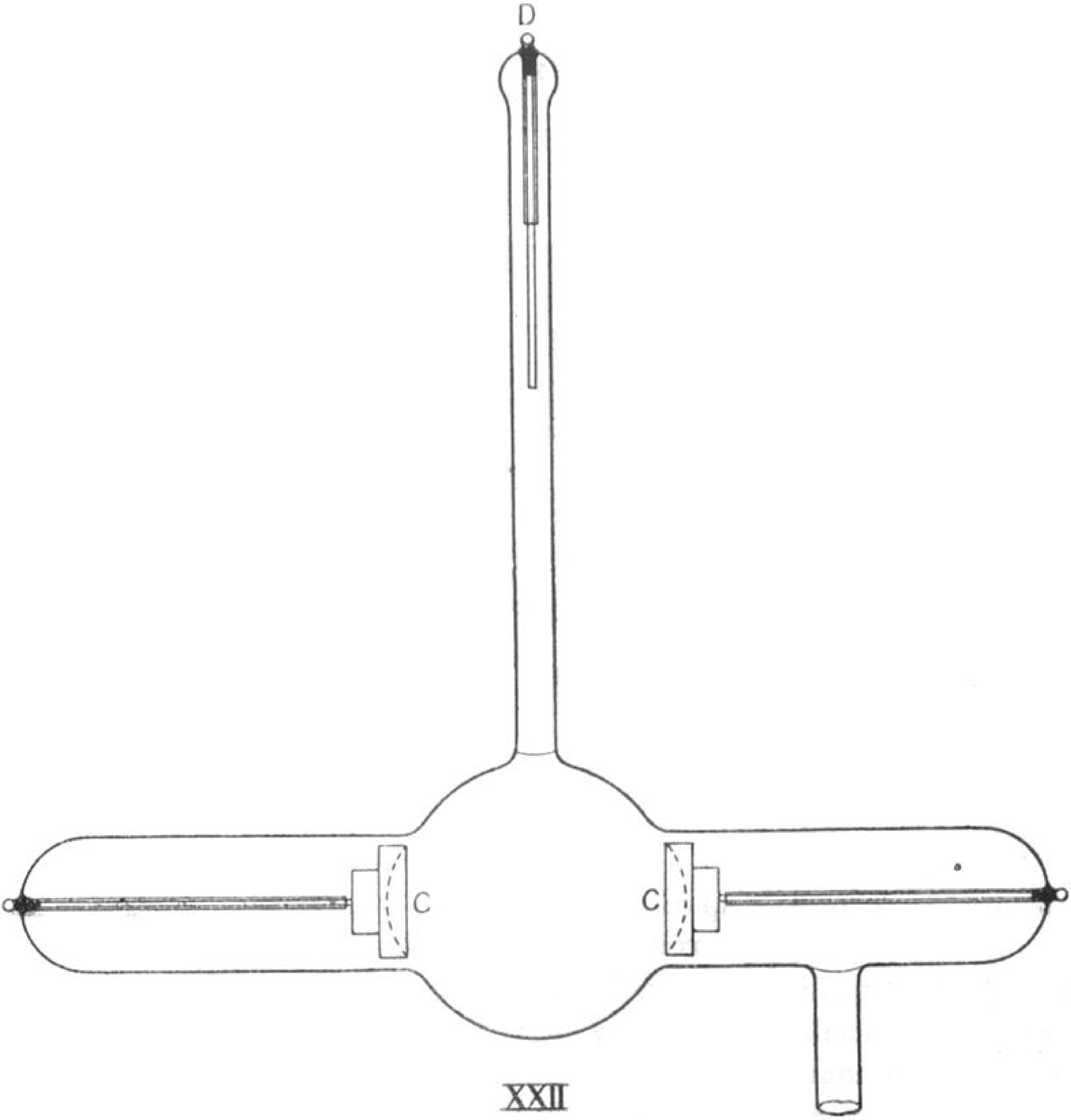
A
C
–
XII
B
+
B
A
C
–
XIII
B
+
B
A
C
–



XIV
B
+
B
A
C
−
XV
B
+
B
A
C
−
XVI
B
+
B
A
C
−

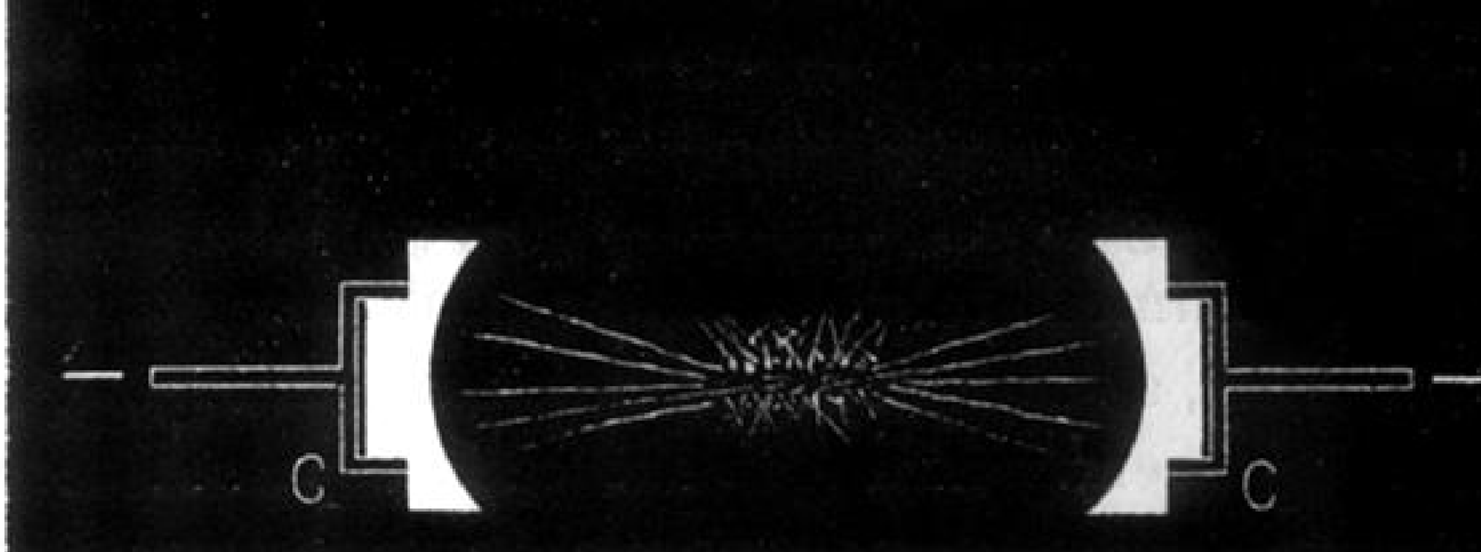

XVII
+
B
A
C
—
B″
B′
B
XVIII
+
B
A
C
—
B″
B′
B


C
C
XX
C
C
XXI



XXII

XXIII



XXIV